Civil Space Technology Initiative

a first step

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NASA

CSTI

OAST

Office of Aeronautics and Space Technology

Contents

This is the first published overview of OAST's focused program, the Civil Space Technology Initiative, which started in FY 1988. This publication describes the goals, technical approach, current status, and plans for CSTI. Periodic updates are planned.

CSTI

The Civil Space Technology Initiative (CSTI) is a vital component of NASA's space R&D program. It is the necessary first step in a focused effort to develop the technology base for future space missions, with primary emphasis on efficient, reliable access to, and operations in, low Earth orbit, and on support of science missions from Earth orbit.

Advanced technology has been a cornerstone of U.S. space activities. Each of our major space programs has been made possible by research conducted many years before the program was started, and in most instances long before it was defined as an actual program. NASA's space technology base has served the country well. At present, however, NASA's space research and technology activities are a small fraction of what they were during the highly productive period of the 1960's and early 1970's. Every recent study of the U.S. civil space program has cited the need for a substantial increase in research and technology. Of particular relevance are the studies conducted by DOD and NASA on future space transportation needs, by the Space Science Board, by the National Research Council, and by the National Commission on Space which, for example, recommended a threefold increase in these areas.

The objectives of CSTI, which will start the revitalization of U.S. civil space technology, are to develop specific technologies critical to accomplishment of relatively near-term, high priority national goals. CSTI, over its projected performance period, will produce substantive capabilities for future mission applications; the products of CSTI will include ground laboratory and/or flight-demonstrated hardware, software, data, processes, and techniques that can be adapted to mission systems of the 1990's.

The program was developed with extensive user involvement from industry, universities, NASA flight program offices, and NASA flight and research centers. Exploiting progress already made in the space R&T program, CSTI is directed at important advances in transportation, operations, and science. CSTI has been organized into these three thrusts composed of a total of ten elements.

The CSTI program is managed from the Office of Aeronautics and Space Technology (OAST) at NASA Headquarters. A Program Manager is responsible for each of the ten elements. Project management is assigned to one of the field centers which leads/coordinates the work of all centers involved in that element. The technical effort is performed at the centers, usually with a combination of in-house and contracted efforts involving industry and universities.

TRANSPORTATION:
- **Earth-to-Orbit Propulsion**
- **Booster Technology**
- **Aeroassist Flight Experiment**

OPERATIONS:
- **Robotics**
- **Autonomous Systems**
- **High Capacity Power**

SCIENCE:
- **Science Sensor Technology**
- **Data: High Rate/ Capacity**
- **Control of Flexible Structures**
- **Precision Segmented Reflectors**

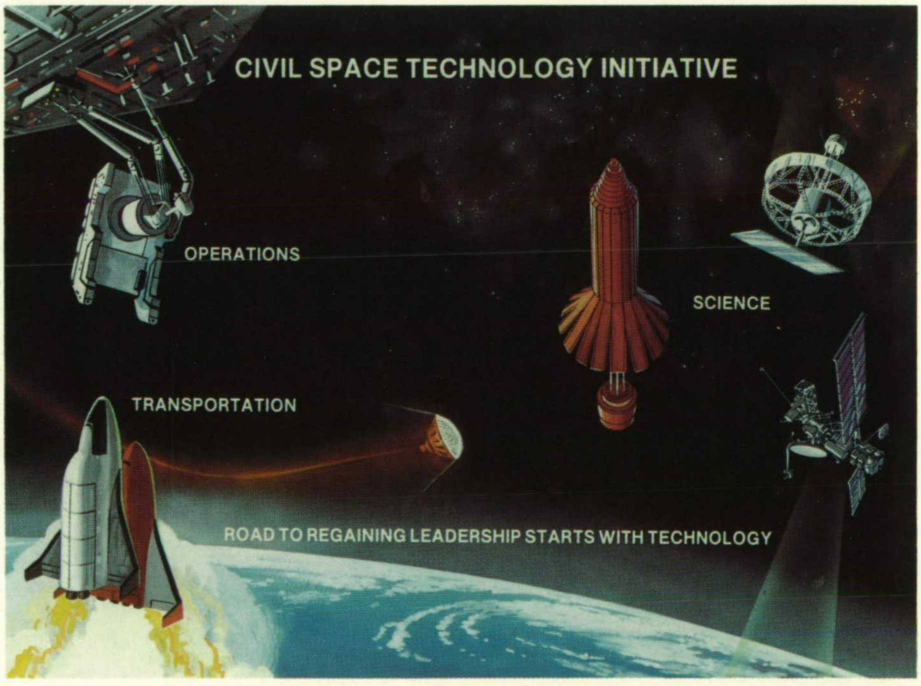
a first step

The program elements serving the needs of future transportation systems address those technologies that will provide safe and efficient access to space. For advanced launch systems, technologies for fully reusable, high performance oxygen/hydrocarbon and oxygen/hydrogen engines will be developed. As alternatives to solid rocket motors for future launch systems and to provide both higher performance and a safe abort option, technology for liquid and hybrid engines will be developed and experimentally validated. A flight research program will verify the technology for orbit transfer aerobraking using atmospheric friction and provide payload doubling relative to propulsion-braked vehicles.

The technology to enhance future space operations will lead to substantial economies and improved safety and reliability for both ground and space activities. The capability of telerobotic systems to service satellites and assemble space structures under supervision from the Space Station, the Space Shuttle, or the ground will be demonstrated in the laboratory. Another major, early focus will be enhanced autonomy of launch and flight operations for the next generation of transportation systems. Validation of increasingly complex autonomous systems technology will provide coordinated control of multiple functions and systems. Experimental verification of energy conversion technology will enable a fivefold increase in electric power from spaceborne reactors such as SP–100.

To support the more effective conduct of scientific missions from Earth orbit, efforts will be directed at improving the spectral range of sensing systems and at creating more efficient means of processing the burgeoning data streams from imaging systems. The development and testing of detectors operating in the submillimeter region will enhance astrophysical and Earth science observations, and solid-state, tunable lasers will sense otherwise undetectable atmospheric constituents. Onboard image processors and optical storage systems will be produced to enable very high rate, high capacity information flow. Cryogenic refrigeration technology will be developed to dramatically improve infrared (IR) detector performance and operating life. Lightweight, dimensionally stable reflectors using multiple, control-coupled elements will create surfaces of micron-precision for optical and radiofrequency observations. Continuation and completion of the Control of Flexible Structures (COFS) flight program will provide analytical tools and predictive methods for the design of future large, lightweight space systems.

CSTI is targeted at the development of specific technologies vital to the next generation of NASA and other U.S. space projects. CSTI will challenge and encourage not only NASA, but the country's aerospace industry and academic community as well. CSTI, like the follow-on Project Pathfinder and other elements of NASA's recovery plans, is a critical step towards resumption of a vigorous space program that will once again be a source of national pride.



Earth-to-Orbit Propulsion

The goal of the CSTI Earth-to-Orbit (ETO) Propulsion element is to provide a validated technology base for the design of high performance, long-life liquid oxygen (LOX)/hydrogen and LOX/hydrocarbon engines. These advanced engines will help provide truly low cost, routine access to space in the future through the development and operation of fully reusable ETO vehicles. This element focuses on extending knowledge and understanding of rocket engine chemical and physical processes so that realistic analytical simulations of internal environments can be made as well as accurate predictions of steady and unsteady loads, material behavior, structural response and failure mechanisms. Effort is also being expended on technologies for reducing ground operations costs and ensuring safer, more reliable flight operations through the technology development of on-board integrated health monitoring and control systems. The ETO program consists of four focused subelements.

Subelements

- Subscale Components
- Large-Scale Combustion Devices
- Large-Scale Turbomachinery
- Health Monitoring/Controls

Lead Center: **George C. Marshall Flight Center**

Research under the Subscale Components subelement is directed towards the initial development of fundamental analytical techniques and advanced design concepts at the subcomponent and subscale component level. Where appropriate, early evaluations of advanced subcomponent designs, such as turbine blades, pump bearings and seals, and sensors, will be accomplished through installation and testing of these subcomponents in a technology testbed (nonflight SSME) currently being put in operation by the Office of Space Flight. In addition, the planned testing of a highly instrumented testbed engine will generate an early experimental data base that will provide initial limited validation of some of the internal environment simulation codes developed to date.

The Large-Scale Combustion Devices work will involve verifying injector, combustor, and nozzle design concepts that promise high performance, high reliability, and long service life. An experimental data base will be generated in the areas of combustion, cooling, and heat transfer, which will be used to validate computer codes developed in the Subscale Components subelement.

Similarly, the objective of the Large-Scale Turbomachinery effort is to validate design and analysis tools developed in the Subscale Components subelement through the design, fabrication, and testing of highly instrumented interchangeable turbomachinery assemblies. Technology development will involve generating an experimental data base over a wide range of operating conditions with alternative design concepts in order to develop design methodology for turbopump assemblies possessing predictable design margins, subcomponent performance, and operations.

Health Monitoring and Controls activity will focus on defining system architecture as well as critical component performance requirements, including sensors, electronics, real-time engine simulation models, expert systems, controller functions, and control valves and actuators. The focus of the system definition effort will be on providing the capability to monitor high wear rate components in order to schedule maintenance on a need basis rather than time, on automating preflight servicing and checkout procedures,

and on providing in-flight fault-tolerant engine operations. Components will be assembled into an integrated health monitoring/control system using the technology testbed as a vehicle of convenience for evaluating and demonstrating system performance, operation and response.

Technology development has been underway for several years and progress has been made in the development of improved analytical techniques and design methodology for high design margin, high performance reusable engine components. A number of technology products, including advanced instrumentation, diagnostic sensors and advanced turbine blades are ready for early verification testing in the technology testbed. In the near future, work will begin on the design and fabrication of large-scale validation hardware. In the long term, the program will provide a comprehensive technology data base that will support the development of future ETO engines.

For additional information on this element, please contact:

Propulsion, Power, and Energy Division (Code RP)
NASA Office of Aeronautics and Space Technology
Washington, DC 20546
Phone Number: (202) 453–2847

Deliverables

Analytical methods and validated subsystem codes for Earth-to-Orbit Propulsion, including

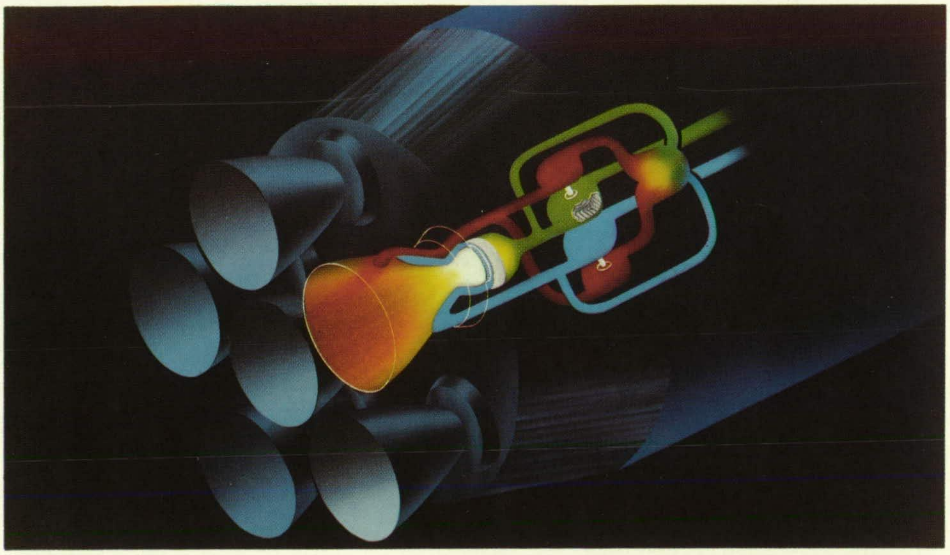
- High pressure combustion, stability, heat transfer and nozzle flow models
- Multistage turbine, hot gas flow computational fluid dynamics codes
- Bearing, fluid dynamics, and rotordynamics models
- Combustion models validated in large-scale hardware, internal environment simulation models and codes
- Low cycle/high cycle fatigue interaction life prediction models

Ground tested, **large-scale advanced devices**, including

- 3000- to 5000-psia combustion pressure gas generators with 95 percent combustion efficiency
- 100-mission-life turbopumps, high turbine and pump efficiency (2000 to 6000 psia, 3-to-1 flow range)

Health monitoring components, devices, and models, such as

- Advanced flowmeters, pressure transducers, bearing wear detectors blade anomaly detectors, and plume anomaly detectors
- Sensors, electronics, expert systems, real-time engine simulator models



Artist's concept of the critical components in an advanced booster engine

Booster Technology

The goal of the CSTI Booster Technology element is to develop the technologies for alternate propulsion concepts for the Space Shuttle Solid Rocket Booster (SRB) having a safe-abort option, the ability to tailor thrust, and the potential for enough additional impulse to avoid the need to operate the Space Shuttle Main Engines (SSME's) at greater than 100 percent power level. The current inability of the SRB's to terminate thrust on command has led to consideration of alternative boosters, of which two are being analyzed.

Subelements

- Pressure-Fed Liquid (PFL) Booster
- Hybrid Booster

***Lead Center:* George C. Marshall Space Flight Center**

The Pressure-Fed Liquid (PFL) Booster program will address technology areas unique to low pressure, high thrust propulsion systems and will augment the Earth-to-Orbit (ETO) Propulsion technology activity that is focused on high chamber pressure, high thrust pump-fed systems. This effort will focus on the development of appropriate analytical models and advanced design concepts using laboratory-scale test equipment to acquire needed empirical data. It will then proceed to subscale component level designs for verification and validation testing as well as for developing scaling methodologies. The program will focus primarily on key component technologies, including low pressure combustion performance, stability, and chamber cooling, tank pressurization gas generation, and thrust vector control. In addition, mass fraction enhancements such as fuel gelling and densification may be investigated.

The Hybrid Booster subelement will provide data pertaining to low-cost hybrid (solid/liquid) boosters consisting of a pump or pressure-fed liquid oxidizer and a rubber-based solid fuel. This effort will develop design and analysis models, computer codes and scaling laws derived through a combination of analytical and empirical laboratory and subscale testing. Code validation will be accomplished through subscale test firings. The technology effort will focus on ignition system optimization; grain formulation, performance, burn rate characteristics, strength, and producibility; oxidizer injection and combustion process optimization and scaling; and gas generation for oxidizer tank pressurization.

The implications of using pressure-fed or hybrid boosters with the Space Transportation System (STS), including launch facility impacts, change in flight characteristics, and recovery techniques will be analyzed in vehicle/propulsion interaction studies. Studies will also be initiated to analyze both pressure-fed and hybrid booster propulsion designs as defined by vehicle systems analysis studies. Then technology activities focused on representative configurations will be started.

Future goals are geared toward the achievement of large-scale static test firings, in the 750,000-pound thrust level class, to generate a demonstrated technology data base for pressure-fed or hybrid booster development.

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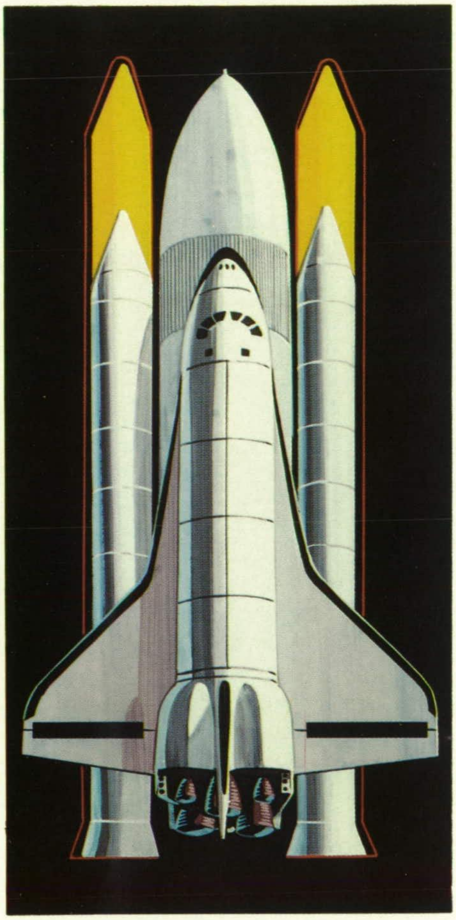
Deliverables

Validated design codes (including scaling methodologies) for pressure-fed **liquid** booster components, such as

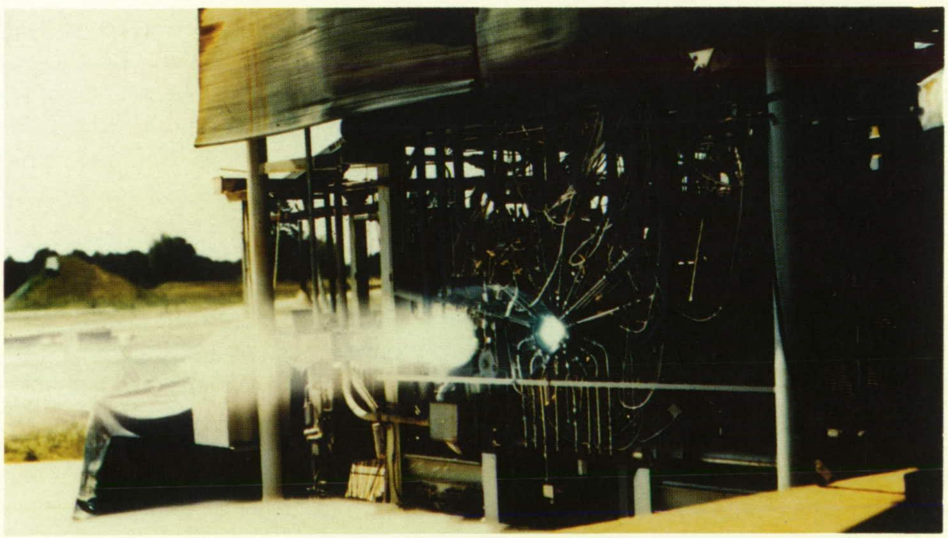
- Combustion, stability, and heat transfer models validated in large-scale hardware
- Main combustors with 95 percent specific impulse efficiency and stable combustion at two thrust levels (50,000 lb at 300 to 800 psia and 750,000 lb at 300 to 800 psia)
- Gas generators (both LOX rich and fuel rich) with 95 percent combustion efficiencies, uniform gas temperatures, and no carbon release

Validated design codes (including scaling methodologies) for high thrust **hybrid** booster components, such as combustion, regression rate, and heat transfer models. New components to be developed will include

- Cases and nozzles using advanced materials (phenolics, composites, and metallics)
- Fuels with well characterized composition and defined grain boundaries



Conceptual drawing of advanced hybrid boosters compared with current solid fuel boosters



Test firing of an oxygen/hydrocarbon engine which could be used in a pressure-fed booster engine

For additional information on this element, please contact:

Propulsion, Power, and Energy Division (Code RP)
NASA Office of Aeronautics and Space Technology
Washington, DC 20546
Phone Number: (202) 453-2847

Aeroassist Flight Experiment

The goal of the CSTI Aeroassist Flight Experiment (AFE) program is to investigate the critical vehicle design technologies and upper atmospheric characteristics applicable to an Aeroassisted Orbital Transfer Vehicle (AOTV). The key advantage of an aeroassist maneuver versus the all-propellant equivalent is the large saving of weight of propellant which would otherwise be required to perform the braking and/or orbital capture engine firings. In some instances, this weight reduction could account for a doubling of useful payload. Because the flight regime of an AOTV is distinct from that of previous missions and because no ground test facilities are adequate to fully simulate an AOTV reentry, a flight experiment is required to complete the technology analysis.

Subelements

- Carrier Vehicle
- Aerobrake
- Experiments

Lead Center: **George C. Marshall Space Flight Center**

The carrier vehicle includes the structural subsystem, the solid rocket motor (SRM), the reaction control system (RCS), and all the avionics required to support the AFE spacecraft. The carrier structure is the primary structure of the AFE spacecraft and provides the mechanical interface for the aerobrake, the SRM, the RCS, and the avionics systems as well as the interface with the airborne support equipment (ASE).

The aerobrake system is composed of a blunted, raked cone aluminum structural element covered by shuttle-type thermal protection system (TPS) tiles that provide protection during the atmospheric drag braking in the upper levels of the atmosphere on return to low Earth orbit. Attached to the periphery of the raked cone is a skirt, that is also protected with TPS tiles, which provides an appropriate aerodynamic fairing to reduce base heating. Attachment points are provided on the inner skirt region to interface structurally with the carrier vehicle. Instruments are mounted at various locations on the aerobrake.

The AFE objectives include providing a flight data base for definition of the environment in which an AOTV must fly, including the radiative and convective heating both to the forebody and to the afterbody region of the blunt aeroshell. The program will provide the means to verify computational flow field codes, both through specific measurement of gas and wall parameters and through performance data obtained during a simulated trajectory of an AOTV returning from geosynchronous Earth orbit. Finally, the program will demonstrate the state-of-the-art guidance, navigation, and control techniques for flying vehicles with low lift-to-drag ratios in a variable density atmosphere and the performance of candidate thermal protection system materials and surface coatings in the AOTV flight regime.

Fourteen experiments presently have been identified as candidate experiments. Five of these have been designated as critical experiments. These five are (1) Radiative Heating Experiment, (2) Wall Catalysis Experiment, (3) Forebody Aerothermal Characterization Experiment, (4) Pressure-Distribution/Air Data Systems, and (5) Base Flow Heating Experiment.

The other nine experiments are (6) Microwave Reflectometer Ionization Sensor, (7) Alternate Thermal Protection System, (8) Heat Shield Performance, (9) Aerodynamic Performance Experiment, (10) Plasma Ion and Electron Concentration Experiment, (11) Aft Flow Ionization Experiment, (12) Afterbody

Radiative Experiment, (13) Rarefied-Flow Aerodynamics Experiment, and (14) Ion Mass Spectrometer Experiment.

The actual hardware described earlier in this section will be assembled into a free-flying, autonomous, Space Shuttle launched and recovered spacecraft. It will simulate reentry at geosynchronous transfer orbit velocities by using a solid rocket motor (the main propulsion system) to increase the orbital energy of the spacecraft. The experiments will be placed at various locations on the spacecraft and will gather entry data during the atmospheric pass.

Work to date includes the design and analysis of preliminary aerobrake concepts. The Preliminary Requirements Review Board will meet in August 1988. In addition, in the near term, Preliminary Design Reviews will be held for the AFE mission peculiar equipment and the aerobrake.

For additional information on this element, please contact:

Flight Projects Division (Code RX)
NASA Office of Aeronautics and Space Technology
Washington, DC 20546
Phone Number: (202) 453–2835

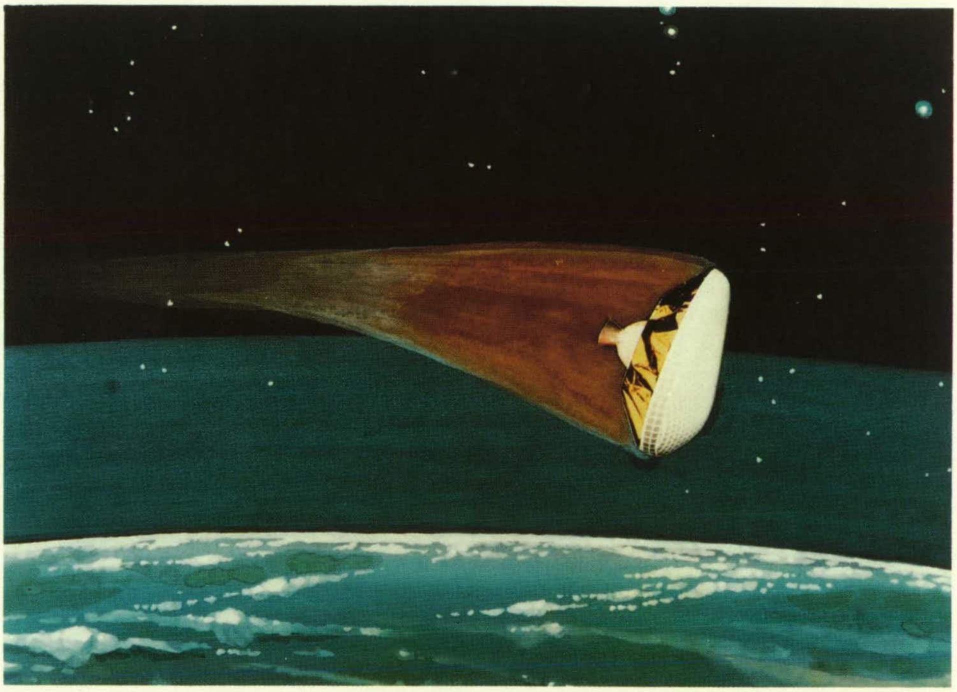
Deliverables

Flight experiment data base for the critical aerothermodynamic parameters including

- Radiative heating levels
- Wake flow base heating levels
- Aerodynamics and control characteristics
- Wall catalysis effects

Aerothermodynamic/thermodynamic **flight-validated computational fluid dynamics codes**, for design guidelines for minimum weight, aeroassisted space transportation vehicles

Alternate thermal protection system materials to permit development of lightweight flexible drag-device concepts



Conceptual drawing of the AFE spacecraft passing through the Earth's atmosphere

Robotics

The overall goal of the CSTI Robotics element is to develop the technology base required to evolve from teleoperations to telerobotics. To perform both complex and mundane tasks more efficiently and safely, telerobotic systems will be used for space assembly and construction, satellite servicing, and platform maintenance and repair. The Robotics element is made up of five core technology subelements and a sequence of laboratory demonstrations.

Subelements

- Sensing and Perception
- Planning and Reasoning
- Control Execution
- Operator Interface
- System Architecture and Integration
- Integration Telerobotic Testbed

***Lead Center:* Jet Propulsion Laboratory**

The goal of the Sensing and Perception activity is to create and maintain a unified world model of a telerobot's surroundings based upon multiple sensory modes, and to enable it to conduct maintenance, repair, and assembly tasks. Force-torque, grasp-force, tactile, and proximity data are needed to provide feedback to teleoperated systems.

The objective of the Planning and Reasoning analyses is to develop knowledge-based systems for intelligent command and control in support of applications in telerobotics and system autonomy. Expert systems will be developed to aid in the evolution from teleoperated systems to robots.

The Control Execution activity will result in the design, development, and evaluation of an advanced computer-controlled drive system with high servo-mechanism rates, highly efficient distributed microcomputer systems for manipulators equipped with smart end-effectors, and computer serviceable smart end-effectors equipped with sensors. Control execution is a key element in the implementation of interactive automatic and manual telerobotic systems.

The goal of the Operator Interface effort is to develop the technology for telerobot control station design which will enable a human to control the telerobot at increasing levels of supervisory control. A quantitative understanding is needed of the increased operational capability that can be achieved through various sensory feedback, display, and control options.

System Architecture and Integration research will result in the development of architecture for integrating the components of telerobots into highly intelligent and operationally capable machines. Plans include development of a test facility for evaluation of advanced manipulator designs and establishing a configuration and performance data base to assist in the test and evaluation of integrated systems.

The Integration Telerobotic Testbed at JPL is a laboratory telerobotic system that integrates state-of-the-art technology and developments from the core technology subelements. The testbed provides periodic evaluations of the evolving capability in telerobotics, performance data, a design data base, and a research tool for telerobotic architecture and integration. In addition, the testbed provides software and hardware to the Flight Telerobotic Servicer at the Goddard Space Flight Center.

Long-term goals for Robotics include developing mobile telerobotic vehicles, autonomous and tele-operated control of seven-degrees-of-freedom arms, laser sensing techniques, computer-aided design/ artificial intelligence planning techniques, and error detection and recovery algorithms.

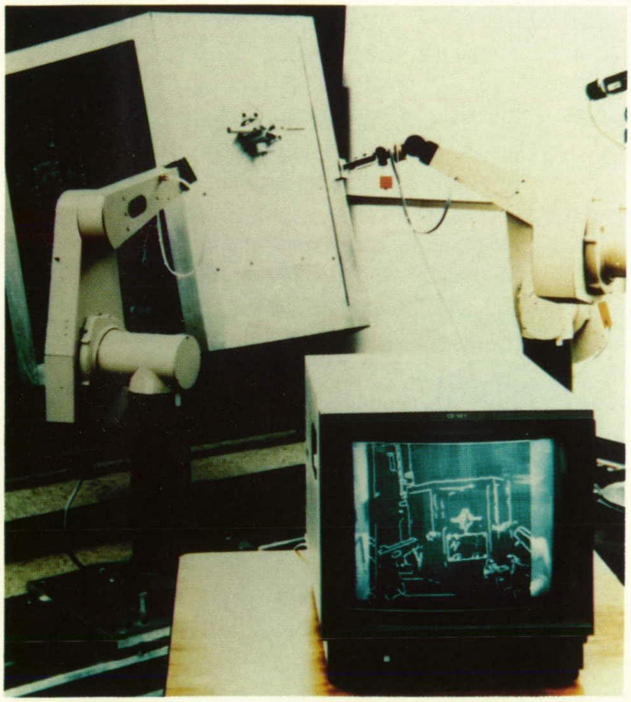
Deliverables

A ground demonstrated, **integrated laboratory telerobot** that combines the immediacy of execution of teleoperation with the efficiency and precision of supervised autonomy, and is capable of

- Stopping a slowly spinning spacecraft
- Simple spacecraft servicing
- Operating in an uncertain, cluttered environment
- Coping with internal faults
- Reacting to a dynamic environment

Advanced technologies for the Space Station **Flight Telerobotic Servicer** including

- System architecture
- Testbed software and taskboards
- Force reflecting hand controllers
- Flight-like manipulator arms and software
- Machine vision subsystem



An advanced dual-arm manipulator that has visually tracked a simulated satellite

For additional information on this element, please contact:

Information Sciences and Human Factors Division (Code RC)
NASA Office of Aeronautics and Space Technology
Washington, DC 20546
Phone Number: (202) 453–2747

Autonomous Systems

The goal of the CSTI Autonomous Systems element is to develop, integrate, and demonstrate artificial intelligence (AI) technology for NASA missions. As future space missions become more complex, it will become necessary for operations to become more efficient. The element objectives will be accomplished by four core technology research subelements closely coupled with several major demonstration projects.

Subelements

- Planning and Reasoning
- Control Execution
- Operator Interface
- Systems Architecture and Integration
- Demonstration Projects
  - Space Station Testbeds
  - Specific Domain Demonstrations

***Lead Center:* Ames Research Center**

Core technology research in Planning and Reasoning will result in the development of advanced computational reasoning methodologies in the following areas: (1) reasoning under uncertainty, (2) learning, (3) causal modeling, (4) knowledge acquisition, (5) advanced planning methods, (6) cooperating knowledge-based systems, and (7) validation methodologies.

Other core technology research efforts include Control Execution, which will develop a mathematical theory that enables the design of symbolic controllers for dynamic systems, and Operator Interface, which will develop human/machine interfaces that will enable "natural" communication with intelligent, autonomous space systems. The goal of Systems Architecture and Integration is to develop systems concepts required for the implementation of robust knowledge-based systems.

The Demonstration Projects provide a means in realistic operational environments to evaluate and validate concepts developed through the scientific research and engineering development of the core technology. These demonstrations of systems autonomy technology will be instrumental in establishing credibility and user confidence in the technology. Initially, knowledge-based control of the Space Station's thermal control system will be investigated to test fault diagnosis and correction advice on anticipated faults, incipient failure prevention through trend analysis, and descriptive explanation displays. Following this, the next demonstration will test coordinated simultaneous control of two complex systems, the thermal control and power control systems of the Space Station.

To ensure that generic technology aimed at ground and low Earth orbit applications is applicable to other NASA missions, a set of Specific Domain Demonstrations has been planned. The first, Shuttle Flight Control Room Operations, will participate in Flight Control operations at the Lyndon B. Johnson Space Center during Space Transportation System (STS) missions. The Launch Operations demonstrations at the John F. Kennedy Space Center will include autonomous diagnostics and control of the Shuttle Orbiter's Environmental Control System. Approaches to automating electrical and pneumatic functions of the Space Shuttle including prelaunch and postlaunch operations will be

explored. Finally, the Mission Operations Ground Data Systems demonstration at the Jet Propulsion Laboratory will develop technologies to enable and enhance the multimission monitoring and diagnosis of ground data systems for unmanned spacecraft.

A number of tasks have already been completed. The Autoclass System for classifying large data bases has emerged from long-term research in machine learning. The Operator Function Model Expert System has been implemented to provide design assistance by capturing essential task-operator characteristics. Progress has been made on development of a spaceborne Very High Speed Integrated Circuit symbolics multiprocessor which will execute numeric and symbolic processing for large knowledge-based systems. Automated mission scheduling for the Pioneer Venus spacecraft has also been demonstrated. A prototype Thermal Management Subsystem Control System using an artificial intelligence knowledge base is being developed.

Near-term goals include developing coordinated real-time decision-making schemes using multiple knowledge sources, machine learning, uncertainty planning, and software verification and validation methodologies. Future objectives include developing reconfigurable fault-tolerant systems and hierarchical and distributed control systems for multiple subsystems, systems integration of numeric and symbolic functions, and demonstrations of multiple subsystem control systems.

Deliverables

Ground demonstrated, **knowledge-based expert systems**, capable of procedural planning and corrective action, and fault detection and diagnosis for

- Aiding the Integrated Communications Officer (INCO) in Mission Control Center
- Control of Space Station thermal control and power testbeds
- Control of Shuttle Environmental Control System during launch operations

Advanced technology capability in the areas of **planning and reasoning, control execution, operator interface, and systems architecture and integration** leading to

- Real-time artificial intelligence based systems
- Machine learning
- Management of uncertainty
- Control of multiple knowledge-based systems
- Artificial intelligence system verification and validation

Additional information on this element, please contact:

Information Sciences and Human Factors Division (Code RC)
NASA Office of Aeronautics and Space Technology
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Phone Number: (202) 453–2747

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High Capacity Power

The goal of the CSTI High Capacity Power element is to develop the technology base needed to meet the long duration, high capacity power requirements for future NASA space initiatives. Efforts will be focused on increasing system thermal and electric energy conversion efficiency at least fivefold, and on achieving systems that are compatible with space nuclear reactors. The technology program is composed of six subelements.

Subelements

- Free-Piston Stirling Engine
- Thermoelectric Converters
- Thermal Management System
- Power Conditioning, Control, and Distribution
- Power System Diagnostics/Fault-Tolerant System
- Environmental Compatibility and Systems Lifetime

Lead Center: **Lewis Research Center**

The Free-Piston Stirling Engine technology effort will involve the design, testing, and analysis of a full-scale, superalloy space Stirling engine. Tests and evaluation of the performance, reliability, component life, and dynamic behavior of an engine operating at 1050 K will enable the later development of an engine capable of operating at 1300 K. This engine will use the SP–100 Ground Engineering System reactor as the heat source. Development of this future engine will increase SP–100 efficiency and power output by a factor of five or more.

The objective of the Thermoelectric Converters effort is to develop a reproducible thermoelectric material that can more than double the conversion efficiency of the standard silicon-germanium (SiGe) material. This will be done through the use of gallium phosphide (GaP) as a dopant additive to the standard SiGe. Thermoelectric conversion systems can offer advantages over higher efficiency dynamic conversion systems in some instances because of the smaller required radiator area, and thus lower system mass and volume.

Thermal Management System analysis will be aimed at reducing the radiator specific mass (kg/kW) of the current SP–100 baseline system by one half. Advanced waste heat radiator concept studies are underway to identify innovative design approaches and technology needs. Research into high temperature, low mass heat pipes, new composite materials, and development of new surface conditioning techniques to improve the emissivity of surface materials will be undertaken.

Power Conditioning, Control, and Distribution research has two goals: to develop radiation-tolerant, high temperature operable components and circuits and to develop fault-survivable power distribution systems for use in high capacity nuclear power systems.

The Power System Diagnostics/Fault-Tolerant System objectives are to develop the fault management technology, sensors, and software to enable safe, autonomous, and long-term operations monitoring of a space power system. These technologies will minimize the potential for operational failures.

The Space Environmental Compatibility and Systems Lifetime technology effort will provide the modeling and analysis capability to enable the design of environmentally compatible space power systems. Analysis of nuclear electric propulsion systems will be included because of their potential role in manned planetary transportation.

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Progress has been made in several areas. An advanced materials development program has been started; a study of the Stirling Space Demonstration Engine reactor is continuing; and studies of advanced thermoelectric materials and processing techniques have begun.

Near-term goals include fabrication and testing of SiGe/GaP doping materials, analysis and design of advanced heat pipe radiators, continued testing of refractory metals and composites, and testing of components for the Stirling engine.

Future objectives include the following: (1) development of a 1300 K refractory metal Stirling engine data base, (2) development of lightweight, long-life heat pipe radiator systems, and (3) development of high temperature, radiation-resistant power control and distribution components. Also, evaluation and analysis will continue on advanced, high temperature and high strength refractory alloys and composites.

Deliverables

Advanced, 25-kilowatt-electric **Free-Piston Stirling Engine** to operate in the 1050 to 1300 K temperature range, with demonstrated

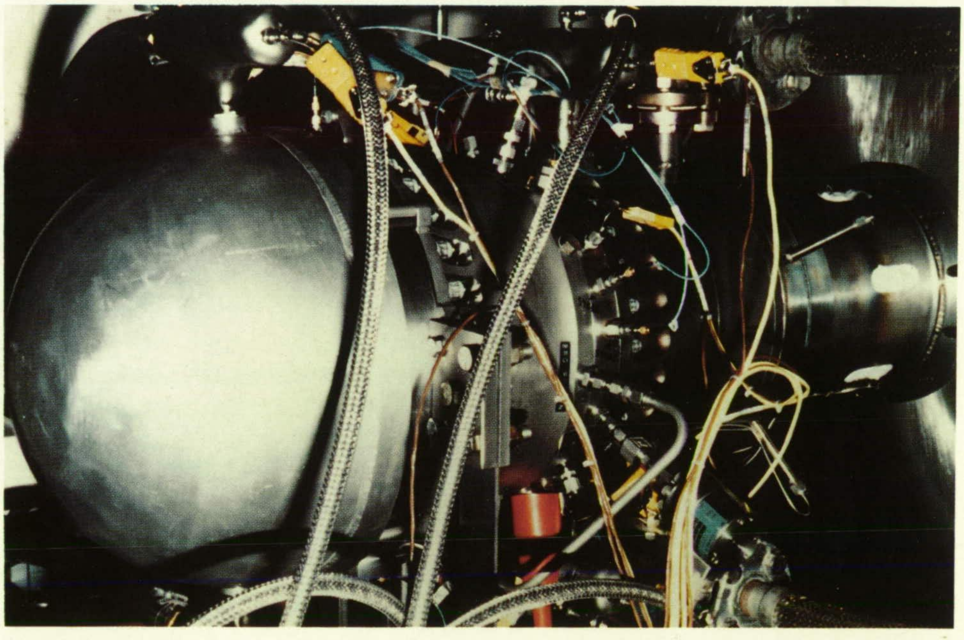
- 25 percent power conversion efficiency
- 10-year life
- 80-watt-per-kilogram specific power

Advanced high temperature (875 to 1273 K) **thermoelectric materials** based upon SiGe doped with

- GaP to demonstrate figure of merit, $Z = 0.85 \times 10^3\ K^{-1}$
- Other advanced dopants to demonstrate figure of merit, $Z > 1.4 \times 10^3\ K^{-1}$

Advanced **thermal management** technology, including

- Development of heat pipes with specific mass >5 kilograms per square meter
- Development of radiators surfaces with 0.85 emissivity without coating



The 1050 K Stirling engine

For additional information on this element, please contact:

Propulsion, Power, and Energy Division (Code RP)
NASA Office of Aeronautics and Space Technology
Washington, DC 20546
Phone Number: (202) 453-2847

Science Sensor Technology

The goal of the CSTI Science Sensor Technology element is to develop the technology base for the development and implementation of scientific sensing instruments for future NASA missions that will investigate our Earth, the Solar System, and the Universe. To avoid absorption caused by the atmosphere, future sensing instruments will operate from Earth orbit, a fact that is accounted for in this research. There are four primary subelements.

Subelements

- Passive Sensing, Detector Technology
- Passive Sensing, Heterodyne Technology
- Active Sensing
- Cryogenic Technology

***Lead Center:* Langley Research Center**

Passive Sensing, Detector Technology and Passive Sensing, Heterodyne Technology research will involve the development of technology for passive remote sensing instruments for space science activities such as astronomy and Earth and planetary sciences in the far infrared (IR) to the submillimeter wave portion of the electromagnetic spectrum. Goals include the development of passive, space-based advanced detectors with the following requirements: sensitivity, spectral coverage, reliability, ruggedness, detective efficiency, clarity of signal (low noise), large array pixel format, and excellent imaging capability, while keeping costs to a minimum.

Active Sensing research has developed crucial measuring techniques in support of atmospheric chemistry and dynamics, climate meteorology, altimetry, and crustal dynamics. The goal is to develop advanced tunable solid-state and gas lasers and accompanying advanced technology in the following: (1) filters, (2) modulators, (3) wavemeter calibration, (4) control systems, and (5) detector receivers. This hardware would then be employed as long-term unattended space qualified instruments for LIDAR (Light Detection and Ranging), DIAL (Differential Absorption LIDAR), and Doppler measuring techniques.

Cryogenic Technology activities will result in advanced Kelvin and sub-Kelvin cryogenic systems to support the sensing instrument components planned for long-term space flight missions. The goals include maximizing component life, temperature stability, reliability, and thermodynamic efficiency at ample heat loads while minimizing cost, weight, and power requirements. Providing the ability to service and replace components is also an objective.

Progress has been made in several areas, although there is still an ambitious schedule of future research. Superconducting-insulating-superconducting (SIS) mixers have been successfully operated. A titanium sapphire laser, for research into lasing transitions due to impurity ions, has been successfully tuned. Also, testing has begun on a submillimeter backward oscillator (SBWO) tube source.

Near-term goals include fabrication and testing of SIS arrays and high temperature SIS thin film junctions, continued studies of SBWO's at high frequencies (1000 GHz), and investigation of holmium-doped materials for eye-safe lasers.

In the future, much analysis is planned, including research in the following areas: (1) incorporating signal processing electronics directly onto the microcircuit chip, (2) investigating new means for harmonic generation of submillimeter radiation, (3) short and long wavelength arrays serving as new optical pump sources for mid-IR wavelength lasers, and (4) improving high capacity cooling at and below 1 K.

Deliverables

Demonstration of advanced **detector system** for the space environment, providing maximum detective quantum efficiency including

- Low noise (100 electrons per pixel or less), 30-micrometer detector arrays
- Far IR to 300-micrometer cutoff wavelength

Submillimeter sensing capability for observing clouds of interstellar dust, such as

- Superconductor-insulator-superconductor (SIS) mixer arrays to 1 terahertz

Demonstrated **tunable** solid-state gaseous (eye safe) **laser** technology for the continuous coverage of the electromagnetic spectrum, to achieve

- 25- to 10,000-nanometer range
- 10 joules per pulse
- 10-hertz repetition rate
- 10^9-pulse lifetime

An advanced **cryogenic cooling system** to survive the space environment, to provide

- Passive cooling for $T < 70$ K
- Vibration free coolers ($T < 1$ K)

For additional information on this element, please contact:

Information Sciences and Human Factors Division (Code RC)
NASA Office of Aeronautics and Space Technology
Washington, DC 20546
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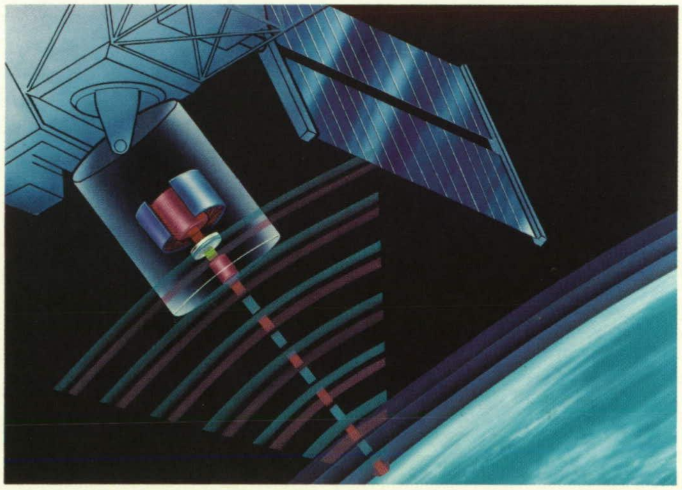

Conceptual drawing of an advanced Earth-sensing instrument

Data: High Rate/Capacity

The goal of the CSTI Data: High Rate/Capacity element is to develop the technologies and systems in high speed, high volume data handling which will be needed to meet the scientific and operational requirements of future missions. Missions such as the Earth Observing System (EOS) will generate large amounts of data. To ensure high scientific returns while keeping operational costs low, it will become necessary to perform recognition, extraction, and transmission of significant observations onboard the spacecraft. This element consists of five subelements.

Subelements

- High Rate System Architecture Definition
- High Rate Image Processor
- Synthetic Aperture Radar (SAR) Processor Development
- General Purpose Components
- Storage Technology Development

***Lead Center:* Goddard Space Flight Center**

High Rate System Architecture Definition goals will be to develop a high rate data system architecture which integrates data handling tasks such as mass storage, sensor specific and generic image processors, control processors and related software, input output buffers, and high speed network elements. This subelement will model the EOS data flow in the areas of onboard data processing, compression, buffering, and down-link transmission. Also, the capability to conduct both preprogrammed and interactive science operations from the ground will be studied. These capabilities will be necessary to support the unique processor and storage requirements of future spacecraft.

The goal of the High Rate Image Processor effort is to define, develop, and demonstrate high rate processor components and algorithms to be used for calibration of sensing instruments, feature extraction, real-time image selection, and data compression. Real-time data processing will increase the scientific return within the limitations of space-to-ground transmission links by selecting those data which are of immediate interest.

Synthetic Aperture Radar (SAR) Processor Development research will include ground demonstrations of a prototype onboard processor. The processor will generate real-time images from space-based radar returns and will perform the post-processing to allow for future data reduction.

The objectives of General Purpose Components research are to develop and demonstrate technologies for fault-tolerant, parallel general purpose system control processors. Processor design will address the encoding, blocking, and control of high rate data to ensure accurate and efficient transmission and retrieval of data.

The goal of the Storage Technology Development effort is to develop a ground-based engineering model of a high capacity (in the terabit range) and high rate (>300 Mbps) erasable optical disk drive and controller for onboard storage and block retrieval of data. Researchers will also evaluate alternatives for increasing the reliability and replaceability of tape recorders.

Accomplishments to date include the following: (1) completion of component technology analysis for a 16-bit space qualified general purpose computer, (2) completion of feasibility studies of onboard SAR and High Resolution Imaging Spectrometer (HIRIS) processors, and (3) successful operation of an optical disk feasibility demonstration

having an erasable media and read/write head.

Near-term goals include starting optical disk recorder brassboard technology analyses and defining the detailed system requirements and architecture for SAR and HIRIS processors.

The long-term objective is to produce, test, and validate flight qualifiable components such as optical disk recorders, SAR processors, and as yet undefined onboard information extraction hardware and techniques.

Deliverables

Processor that will interface with the high rate sensors, and the on-board intelligent systems

- To provide high volume data processing (100 Mbps)
- Very high speed integrated circuit technology
- 10- to 50-megabyte-per-second processing capability
- Data compression capability
  5-to-1 nominal
  20-to-1 potential

A high rate scientific **optical disk recorder** instrument for an on-board data storage system, that is

- 1.6×10^9-byte-per-second transfer rate, capable of high speed read/write operation (>300 Mb/sec), expandable to 1×10^{12}-bit storage capability

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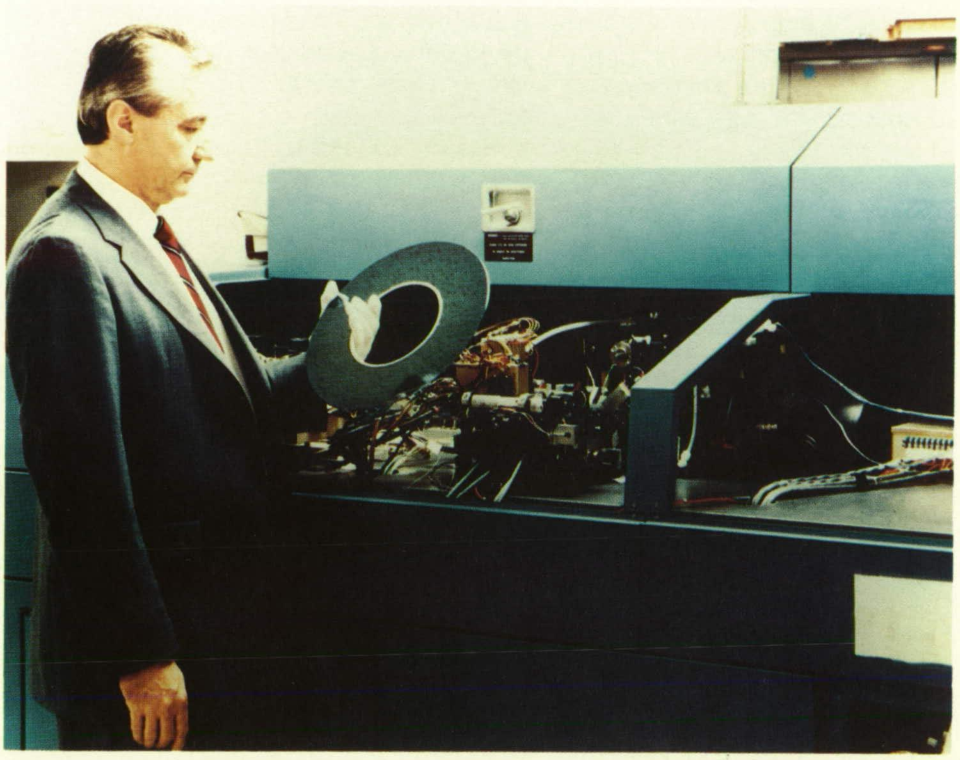


Example of current optical disk technology

Control of Flexible Structures

The goal of the CSTI Control of Flexible Structures (COFS) element is to develop structures and controls technology that will enable the design, verification, and qualification of precision space structures and large flexible space systems. Integrated controls and structures analysis and design methods will be developed and verified through ground test and in-space flight experiments. The program is composed of four subelements.

Subelements

- Design Concepts
- Integrated Analysis and Design
- Ground Test and Methods
- In-Space Flight Experiments

Lead Center: **Langley Research Center**

Innovative Design Concepts, such as active structural elements, adaptive structures, and embedded sensors, will be explored for a broad range of space structures. This activity will involve the development of new sensors and hardware integrated into structural members to perform as flexible space structure.

Analytical methods developed for the Integrated Analysis and Design effort will include developing modeling concepts, dynamic system design, system identification, and simulation studies to model total system performance. Design optimization methods will also be developed, and new analytical tools will be required to address optimal slewing, precision pointing and tracking, dynamic shape control, and precision structural configurations.

The Ground Test and Methods activities include development of new testing concepts involving advanced suspension systems and methods to simulate in-space experiments, hybrid structures, scale models, and new measurement systems. NASA ground test facilities will serve as testbeds for validation of analysis and simulation models as well as a means for exploring advanced structural concepts. Ground tests of scaled flight models or actual flight hardware will provide a means for generating dynamic response and control characteristics which can be verified by actual in-space experiments.

In-Space Flight Experiments will be conducted to validate analytical predictions and ground testing of precision structures and large flexible space systems. Ground testing cannot assure in all cases the accurate prediction of on-orbit performance. For example, ground testing cannot account for situations where gravity deforms structures, overrides low-force control actuators, masks mechanical deadband or distorts accelerometer outputs.

Results of in-flight experiments will provide the validated data base for understanding control/structures interaction (CSI) and will permit the design of stable flexible space structures.

Accomplishments to date include testing of a 20-meter minimast and initial design of a hybrid scale model of a representative Space Station configuration.

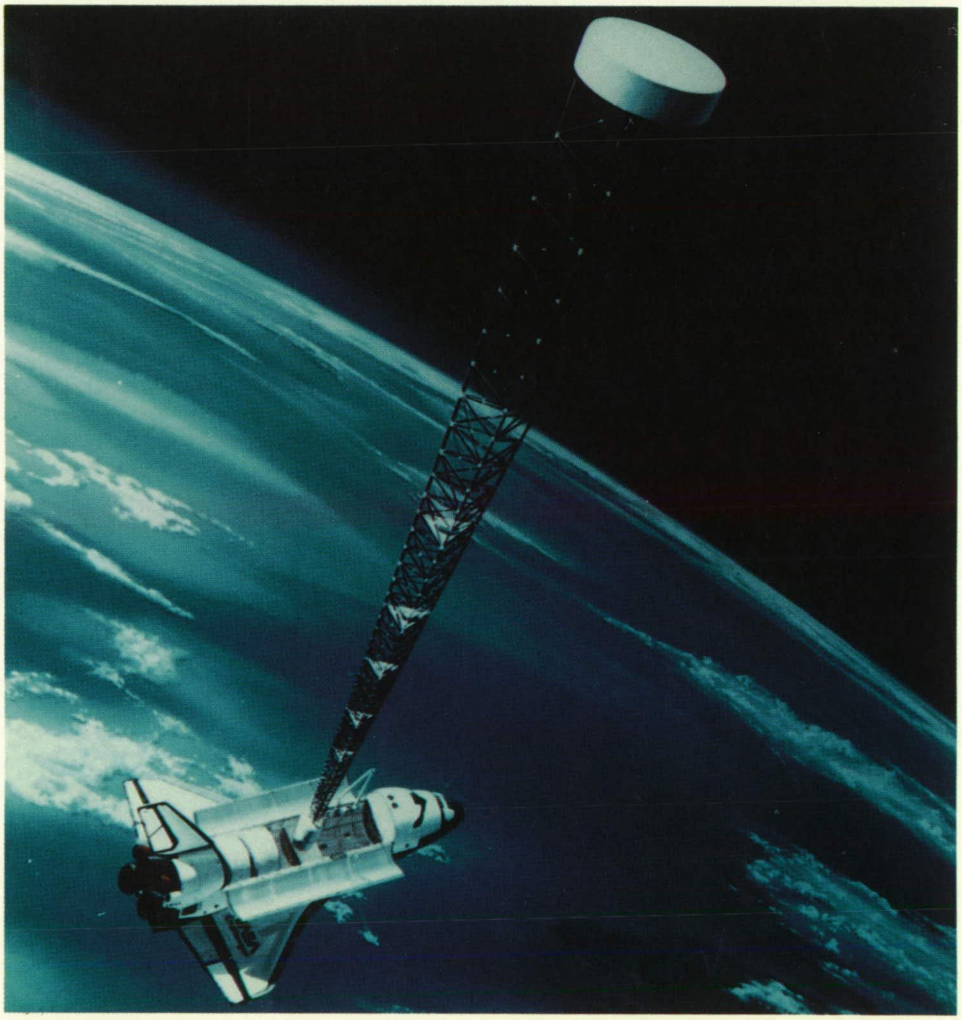
In the near future, integrated control/structures models for flexible space structures will be developed, and new concepts for active structural elements will be established. In addition, development of methods for accurate measurement of small amplitude vibrations and displacements for ground and flight tests will take place together with an assessment of candidate structures for in-space CSI flight experiments.

Long-term goals include development of CSI technology which will lead to ground and flight demonstration of large flexible space structures to validate CSI design and flight qualification methodologies.

Deliverables

Methodology for control/structures integration of large, flexible spacecraft, including

- A unified system for analysis and design to achieve
  - 30 percent weight reduction
  - 400 percent increase in damping
  - 100 percent increase in slew rate
  - significant increase in science returns
- Ground verification of the methodology using large beam structures
- Flight verification of the methodology using the same test articles to obtain the gravity dependent parameters



Truss system deployed for a controls/structures interaction test

For additional information on this element, please contact:

Materials and Structures Division (Code RM)
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Washington, DC 20546
Phone Number: (202) 453–2760

Precision Segmented Reflectors

The goal of the CSTI Precision Segmented Reflector (PSR) element is to develop the materials, structures, and control technology to enable the design of large, lightweight, high precision orbiting astronomical instruments for making deep space observations in the submillimeter (and smaller) portion of the spectrum. Space observatories planned for the future will be much larger and heavier than current systems; therefore, lightweight and space erectable/deployable systems need to be developed. The element objectives are divided into three primary subelements.

Subelements

- Precision Segmented Reflector Integration
- Panel Technology
- Precision Segmented Reflector Primary Structure

Lead Center: **Jet Propulsion Laboratory**

The goal of the PSR Integration effort is to oversee and maintain the program coordination and technology integration, and to conduct system level validation testing. This task will develop advanced methods of multidisciplinary analysis, design, and optimization together with analytical models to predict system performance.

The objective of Panel Technology research is to develop the technologies, in the areas of materials, structural concepts, and testing, needed to create high precision, lightweight (approximately 5 kg/m^2) reflector panels. The key elements for panel development are low weight, low thermal distortion, reproducibility, and space durability. Panel concept development will concentrate on advanced epoxy polymers and panel materials and will include the use of embedded and external actuators to control the overall shape of a panel. Panel fabrication and processing will address all aspects of scaleup and reproducibility. In conjunction with the development of these technologies will be the development of methods for attaching and joining panels to each other and to the supporting structure.

PSR Primary Structure activities will include development of both the supporting erectable/deployable truss concepts and the overall control methodology. The truss concepts will be lightweight and dimensionally stable with high precision joints. In order to maintain surface precision, the truss structure will need to be more precise than is currently being considered for applications to structures such as antennas and the Space Station. The control methodology will address the overall accuracy of the reflecting surface and the response to dynamic disturbances caused by the sun and shade (thermal distortion), power systems, scientific instruments, etc.

Accomplishments to date include the fabrication of a 0.4-meter graphite epoxy honeycomb panel with an approximately 3-micron root-mean-square (rms) surface accuracy.

Near-term goals include constructing a 1-meter panel with 3-micron rms surface accuracy and development of the architecture for a panel alignment control system with submicron accuracy.

The long-term objectives are (1) to develop the technology needed to construct 2- to 3-meter panels and then (2) to demonstrate a multi-segmented system to validate the technology for very large precision segmented reflectors.

ORIGINAL PAGE
COLOR PHOTOGRAPH

Deliverables

Fabricated panels with surface precision and thermal stability, capable of high frequency operation, to demonstrate

- Surface precision: <3 micrometers
- Thermal stability: −75 to 25 °C
- Specific mass: 10 kilograms per meter (including thermal blanket)

A testbed (4 m) version and a 10-meter validation model of a self-deployable, lightweight **structure**, capable of high pointing accuracy and position retention, to be capable of

- Pointing accuracy: <5 micrometers rms

Systems integration methodology for the deployment of precision segmented reflectors in space, including

- Ground test methodology
- Simulated structure control/behavior

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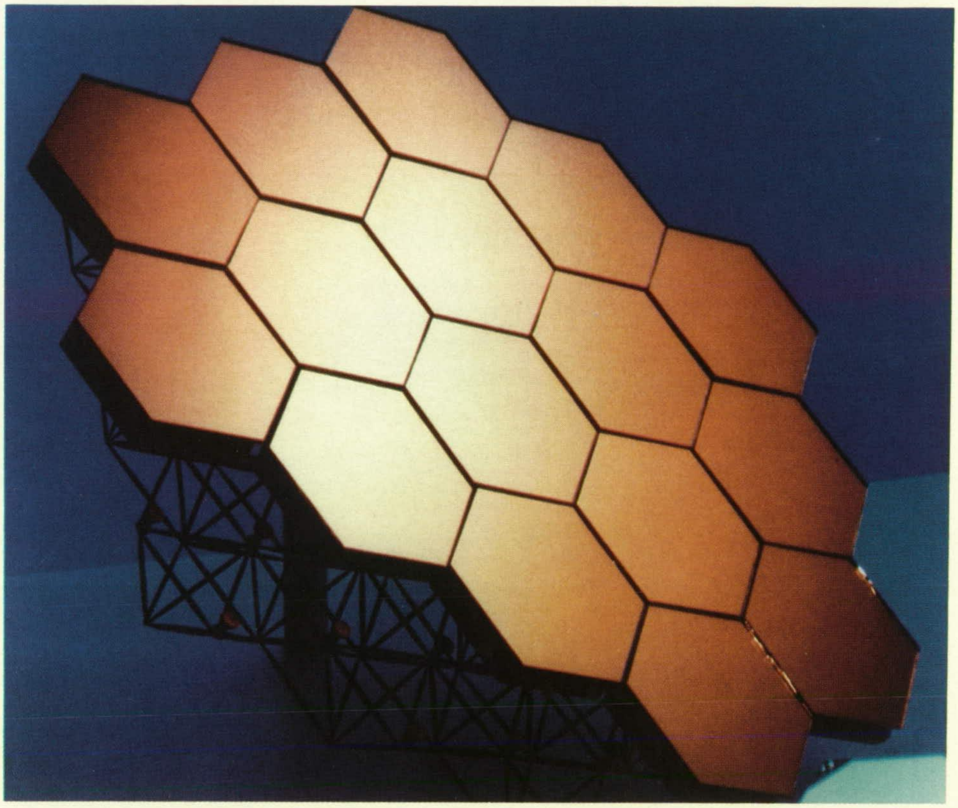

Example of an advanced precision segmented reflector